

THE MULTILAYERED "BLACK MIRROR"

M. M. KOLTUN

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ABSTRACT

Requirements are delineated for the selective optical coatings that are "black" in the visible and "white" in the infrared portions of the spectrum. Spectral and integral optical characteristics are described for four- and six-layer coatings on copper and aluminum consisting of alternating layers of nickel (10 to 15 μm thick) and silicon dioxide (80 to 98 μm thick).

The coatings described feature a solar integral absorption coefficient of between 0.92 and 0.96; the thermal integral absorption coefficient at 30° C is from 0.07 to 0.12. The optical characteristics remain stable during prolonged solar and ultraviolet irradiation at 150° C and at temperatures up to 350° C in a vacuum.

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The selective optical coatings that are "black" in the visible and "white" in the infrared (IR) portions of the spectrum are widely used for the separation of the spectra and for the elimination of visible illuminations that occur in the infrared optical apparatus [1, 2]. Figuratively speaking, the term "black mirror" is derived from its characteristics in the visible and infrared portions of the spectrum. Coatings of the "black mirror" type can be used for boosting the KPD (coefficient of usable energy) device that transforms solar radiation into thermal or electrical energy. Solar thermal electrical converters are of the water and air heater type. The "black mirror" ensures a region of low radiation that has to extend through the whole solar spectrum of 0.2 to 2.5. The region of high radiation of the spectral interval pertaining to thermal radiation from bodies (at 30 to 300 deg) extends from 2.5 to 40 μm .

In addition, the coatings have to possess highly stable optical and mechanical characteristics to withstand prolonged solar irradiation under the conditions found in a vacuum; and, also, these coatings must be able to withstand harsh climatic conditions. The coatings must also adhere well to the surface of solar radiating absorbers that are composed of good heat conducting metals (copper, aluminum, or their alloys).

We developed the multilayered selective coatings consisting of alternating layers of semitransparent metallic films and dielectrics of interfering widths. Because of the lack of optical constants (optical constants for the thin films located in the wide intervals of widths and for the area of the spectrum from 0.2 to 40 μm), the exact calculations of the multilayered systems are rather difficult to determine at present. As a result of innumerable experiments that concentrated on the quality of materials for multilayered coatings, it was determined that thin films of nickel and silica should be used. The nickel and silica were applied in a high grade vacuum from multi-core tungsten evaporators and debiteuses. The nickel and silica also can be

applied using sputtering techniques. Characteristically, films of nickel exhibit a rapid decrease in absorption in the transition from the visible to the infrared area of the spectrum [3]. This characteristic of films of nickel is different from that of films of precious metals and good conducting metals. In earlier experiments, it was observed that films of titanium exhibited the same peculiarities as films of nickel. We observed that films of nickel decrease the penetration of glass plates by 30 to 40 percent in the visible range of the spectrum. At the same time, the films of nickel are transparent to infrared radiation with a long wave of 2.5 to 3.0 μm . Films of nickel having a thickness of 10 to 15 nm were distinctly observed to exhibit an interfering effect. This interfering effect centers around the thickness of the nickel film. At this point, the nickel film becomes translucent to the polished surfaces of aluminum or copper in the ultraviolet and visible regions of the spectrum. Films of silica having a thickness of 80 to 90 nm reduce the reflection from the film of nickel and are transparent in the visible region of the spectrum, and the films of silica are translucent for infrared radiation.

References 1 and 2 describe two- and three-layer coatings. These layers are distributed in the following order, beginning with the surface of the metal: semiconductors-dielectric or dielectric-semitransparent metal-dielectric. We observed that four- or six-layer coatings were more effective. In this case, the layers alternated in the following order, beginning with the surface of the metal: semitransparent metal-dielectric-semitransparent metal-dielectric, etc. The use of these layers is possible if the semitransparent layer is specifically selected from quality metals possessing the selective spectral characteristic of absorption. Nickel and titanium possess this absorption quality.

Figure 1 illustrates the spectral dispersion mirror reflection from the surface of polished aluminum before and after the application of the four-layered coating $\text{Ni-SiO}_2\text{-Ni-SiO}_2$ in the region 0.22 to 0.25 μm , and this is measured on spectrophotometers SF-4 and IKS-14. Also illustrated in the figure is the relationship of the reflection of light to the angle of incidence in the interval spectrum of 0.4 to 1.0 μm . As a result of properly matching a coating to the polished aluminum, the coefficient of absorption for solar radiation σ_s increases from 0.16 to 0.92, but the thermal integral radiation coefficient ϵ^2 increases only to the range of 0.07 to 0.08. As is evident from the figure, the reflection from the surface of a four-layer coating is distinguished by a weak relationship at the angle of incidence

2. Translator's note: ϵ = emissivity.

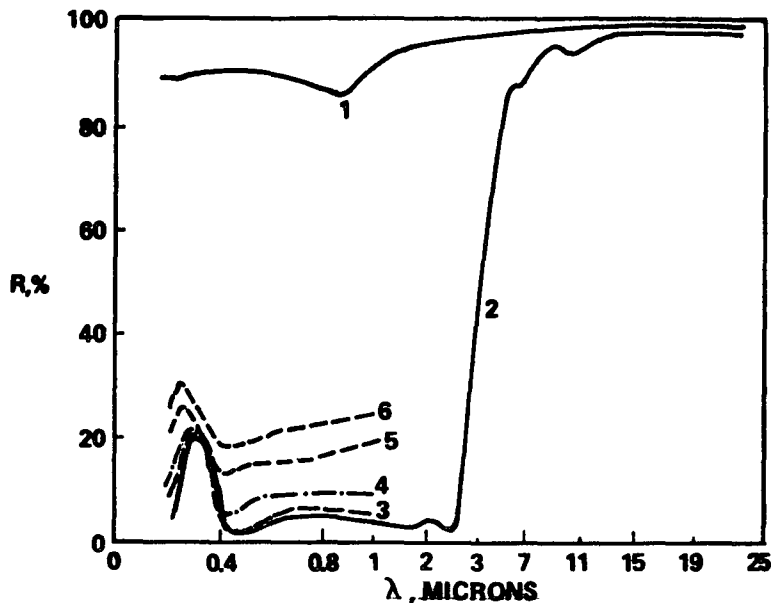


Figure 1. Mirror reflection from the surface of polished aluminum before and after the application of the four-layer coating $\text{Ni-SiO}_2\text{-Ni-SiO}_2$ (the thickness of the nickel is 10 to 15 nm) (the thickness of the silica is 80 to 90 nm), measured from the angle of incidence of light: 2-11, 3-50, 4-60, 5-70, and 6-78.

up to the angle of 50 to 60 deg. This is favorable to surfaces and absorbers of radiation that change their arrangement in an area of significantly decreasing radiation. Diffused reflection from such surfaces did not increase by 1 to 2 percent. This observation was made after taking readings on the spectrophotometers SF-10 and SF-4 with the PDO-1 as an accessory. The following integral coefficients were obtained for the six-layer coating: α_s 0.95 to 0.96; ϵ , 0.11 to 0.12. This six-layer coating is of the following type: $\text{Ni-SiO}_2\text{-Ni-SiO}_2\text{-Ni-SiO}_2$. Likewise, the values α_s and ϵ were obtained by depositing four- and six-layer coatings on the polished copper plates and on nontransparent films of aluminum, copper, silver, and gold. These nontransparent films were obtained by the process of vaporization in a vacuum. Glass slabs and polymer films were used in the vaporization process in the vacuum.

Confirmed results of experiments performed to determine the effects of aging favorably report the stability of these coatings and the ability of these coatings to resist oxidation of the reflecting layers and plates.

The following tests did not alter the optical characteristics of the "black mirror":

1. Prolonged exposure to heat in the atmosphere from 300 to 350° C for a period of 100 to 150 hours.
2. Irradiation by ultraviolet lamps of the type PRK-7 (straight mercury-quartz discharge lamp) for a period of 150 to 200 hours at a distance of 5.6 cm.

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4. Hass, G. and Bradford, Alan P.: JOSA, 47, 125, 1957.

3. Translator's note: possibly Optics and Spectroscopy.